Mini-workshop on BSM at ILC

KAVLI IPMU

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Muon (g-2) in SUSY and future lepton colliders

28/02/2022

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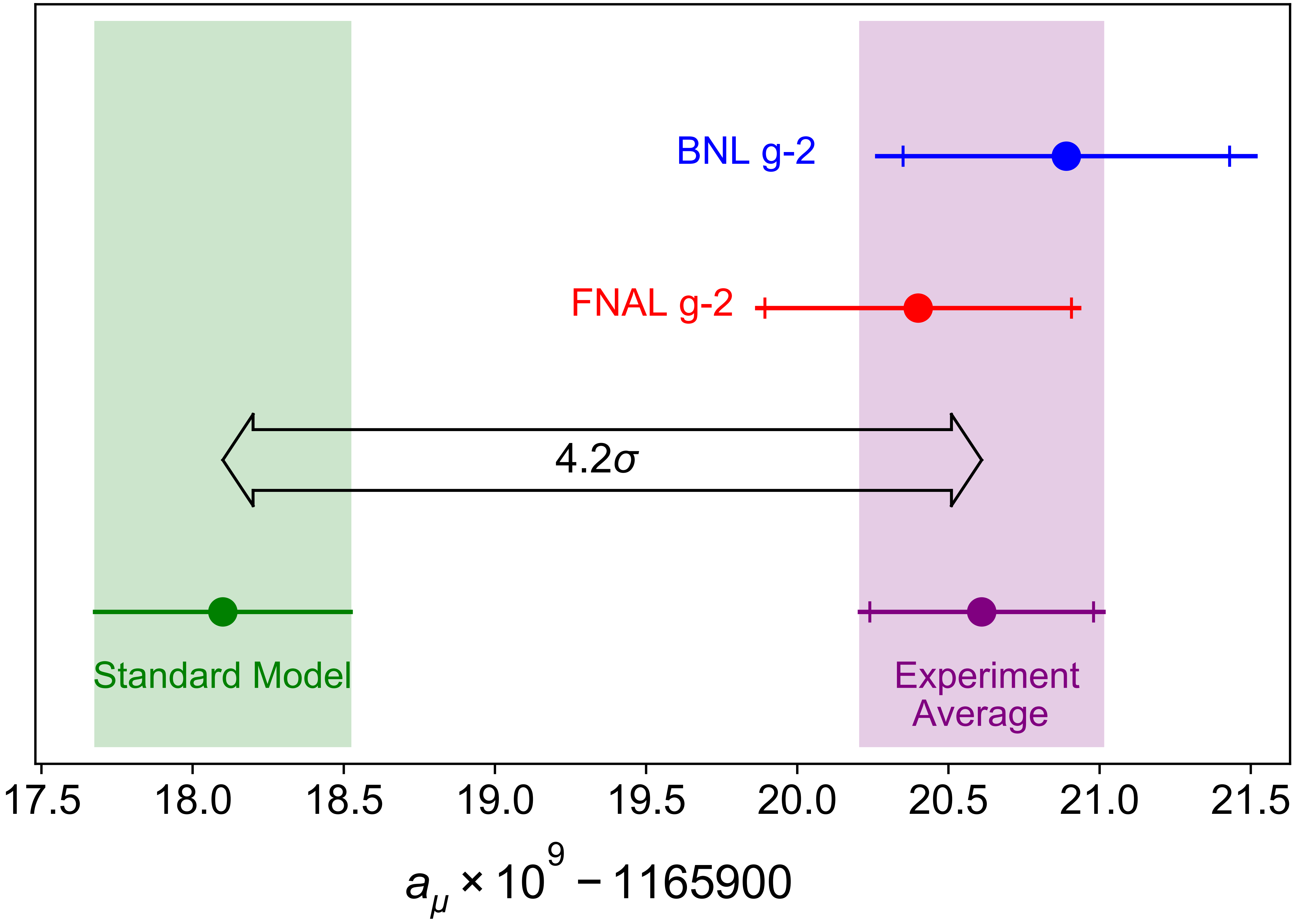
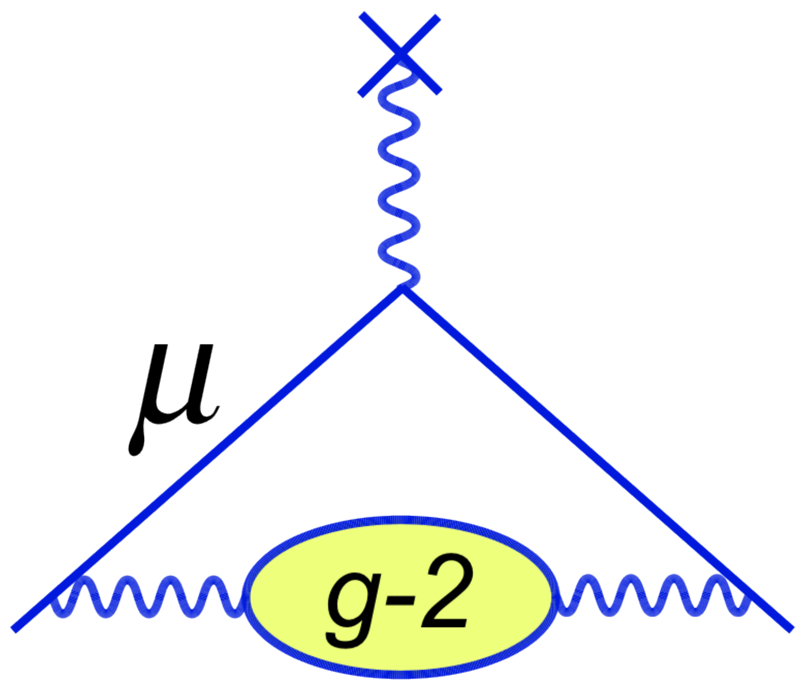
Muon (g-2)



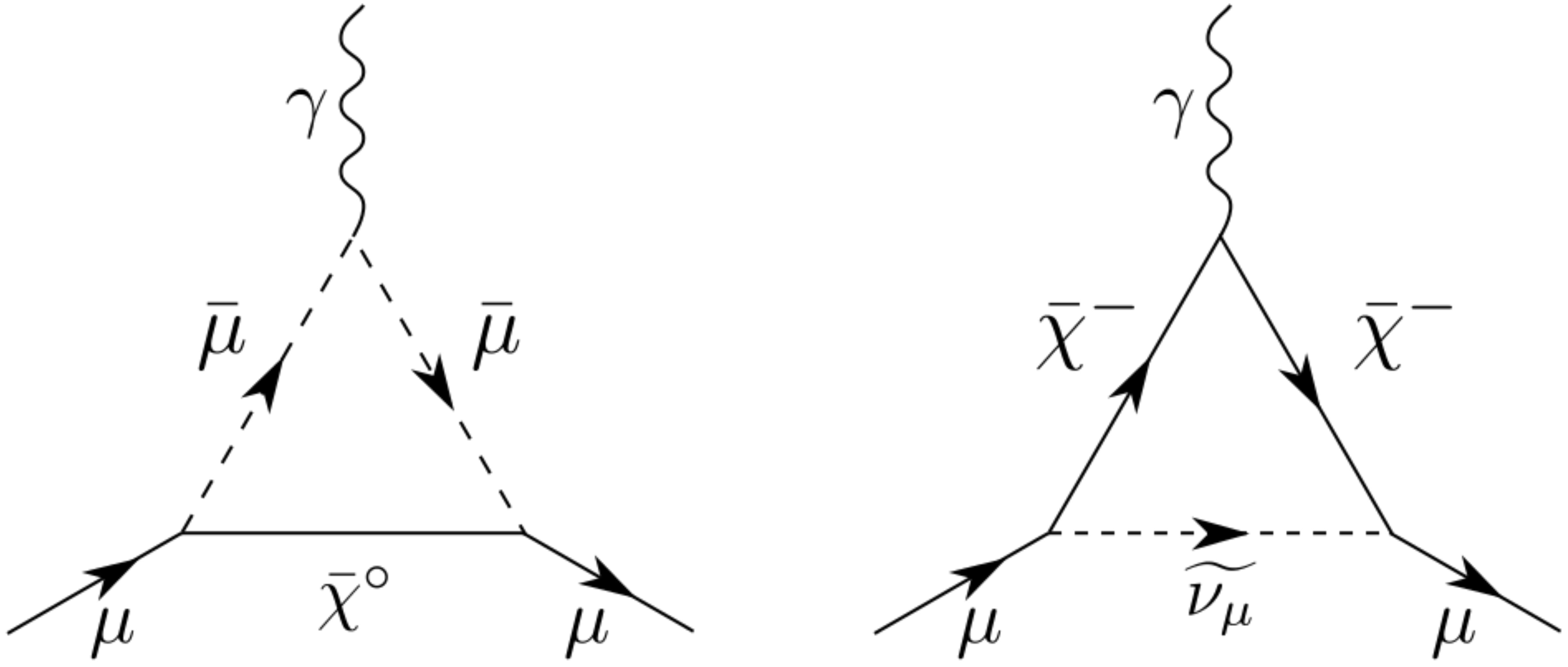


$$a_\mu^{exp} - a_\mu^{theo,SM} = (25.1 \pm 5.9) \times 10^{-10}$$

Muon g-2 experiment at Fermilab aims at 4 x BNL precision

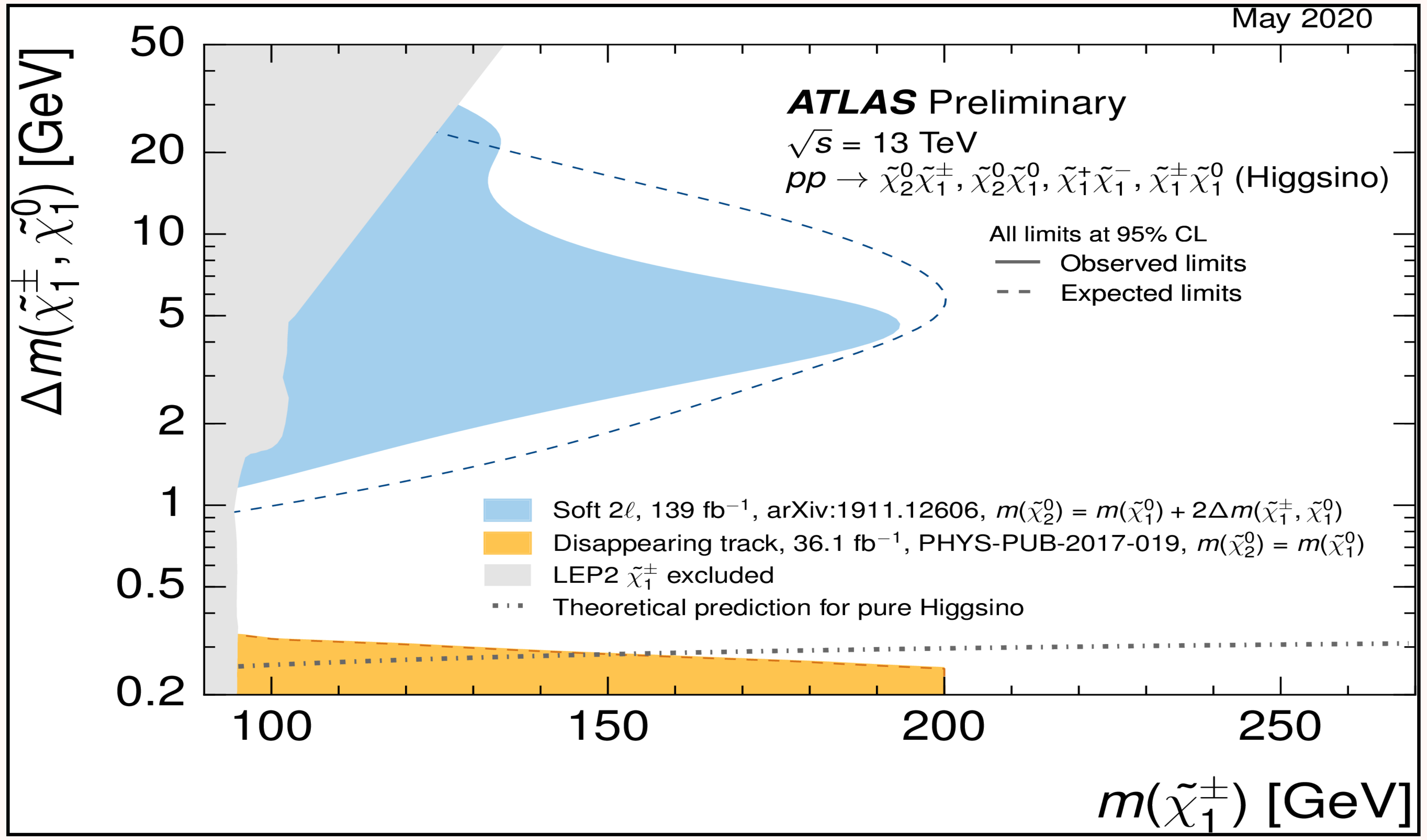
- Abi *et al* PRL '21
- Aoyama *et al* '20

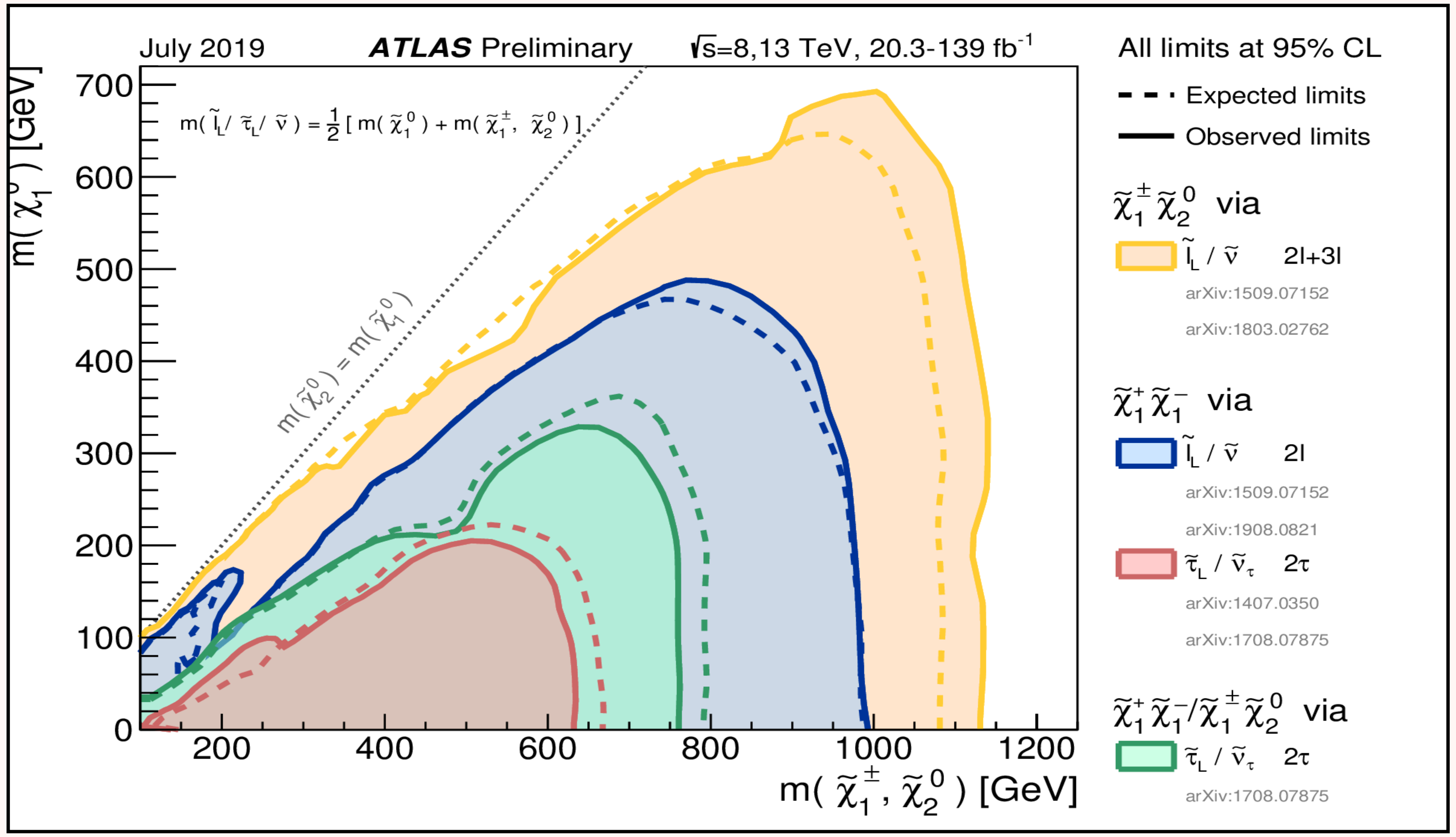
Muon (g-2) in SUSY



- SUSY contributions from Chargino-Sneutrino and Smuon-Neutralino loop
- SM EW 1 loop : $\frac{\alpha}{\pi}\frac{m_\mu^2}{M_W^2}$. MSSM , 1 loop : $\frac{\alpha}{\pi}\frac{m_\mu^2}{M_{SUSY}^2} \times tan\beta$
- SUSY can easily explain anomaly : upper limits on EW super partner masses

Electroweak MSSM at LHC

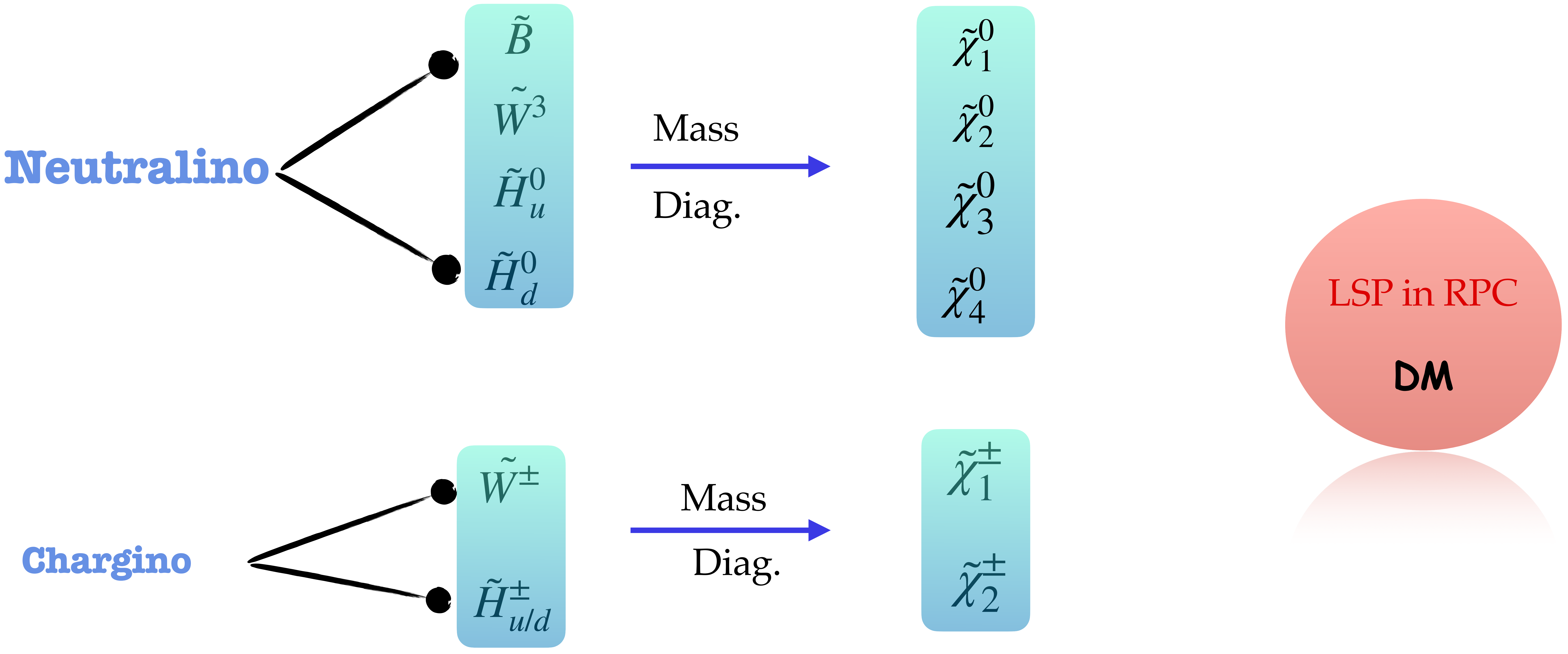




- ★ EW sector may be hiding the key to new physics.
- ★ Modest production cross section, mass bounds from the LHC comparably weak.
- ★ May show up elsewhere : DM experiments, $(g-2)_\mu$ ..

EW Gauginos

Masses and mixing determined by U(1) and SU(2) gaugino masses M_1, M_2 and Higgs mass parameter μ.



FOUR PARAMETERS → $M_1, M_2, \mu, \tan\beta$

Sleptons

Slepton Mass Matrix

$$M_{\tilde{L}}^2 = \begin{pmatrix} m_l^2 + m_{LL}^2 & m_l X_l \\ m_l X_l & m_l^2 + m_{RR}^2 \end{pmatrix}$$

$$m_{LL}^2 = m_{\tilde{L}}^2 + (I_l^{3L} - Q_f s_w^2) M_z^2 c_{2\beta}$$

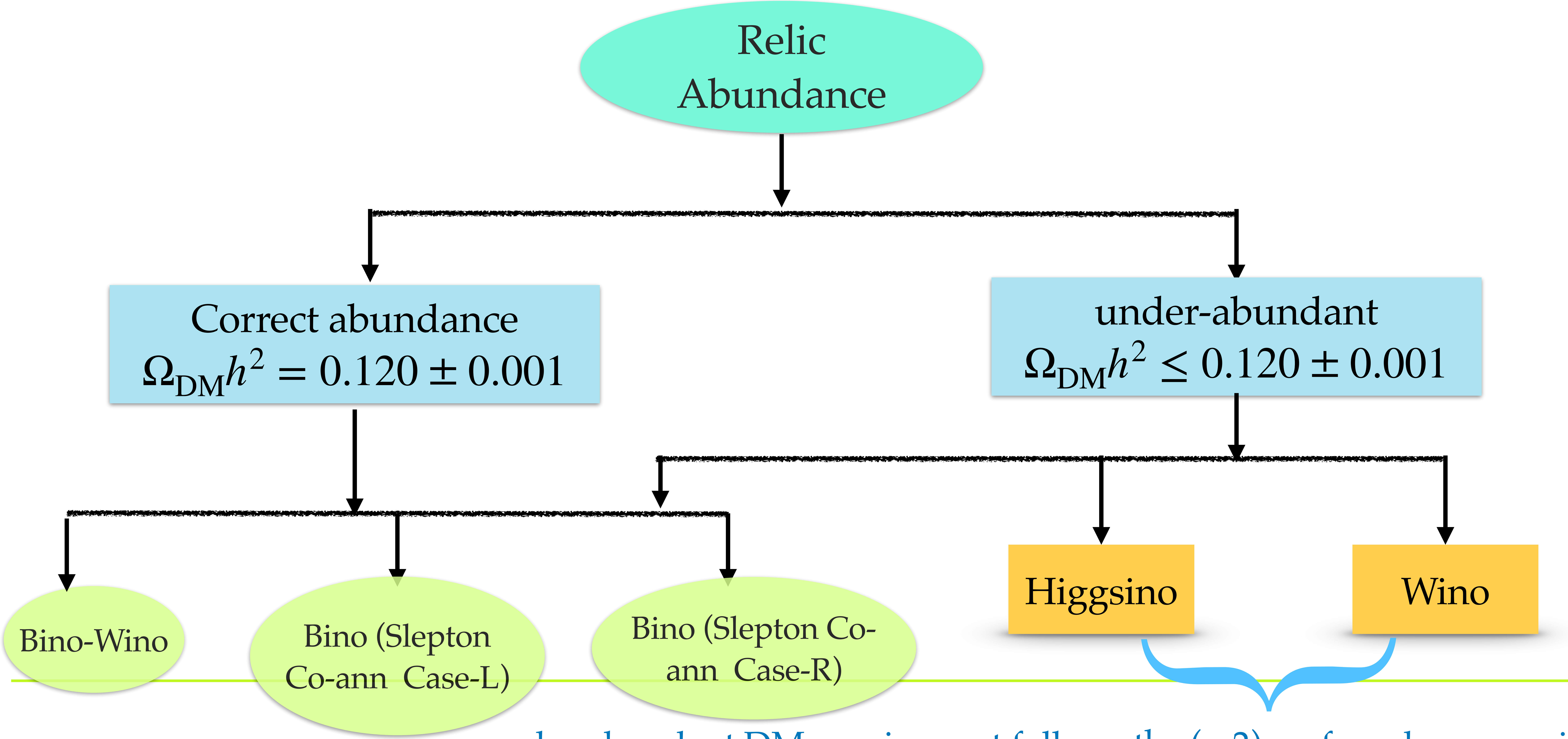
$$m_{RR}^2 = m_{\tilde{R}}^2 + Q_f s_w^2 M_z^2 c_{2\beta}$$

$$X_l = A_l - \mu(\tan\beta)^{2I_l^{3L}}$$

PARAMETERS → $M_1, M_2, \mu, \tan\beta, m_{\tilde{L}}, m_{\tilde{R}}$

First two gens. $m_{\tilde{l}_1} \sim m_{LL}$ $\quad m_{\tilde{l}_2} \sim m_{RR}$

Classification based on DM nature



under-abundant DM requirement follows the (g-2) preferred mass region.

Analysis flow

- **SuSpect** → Spectrum generation
- ↓ **GM2Calc** → $(g-2)_\mu$ @ 2 loop
- ↓ **MicrOMEGAS** → DM observables
- ↓ **CheckMATE** → LHC constraints

Muon (g-2)

$$\Delta a_\mu = (25.1 \pm 5.9) \times 10^{-10}$$

Dark Matter Results

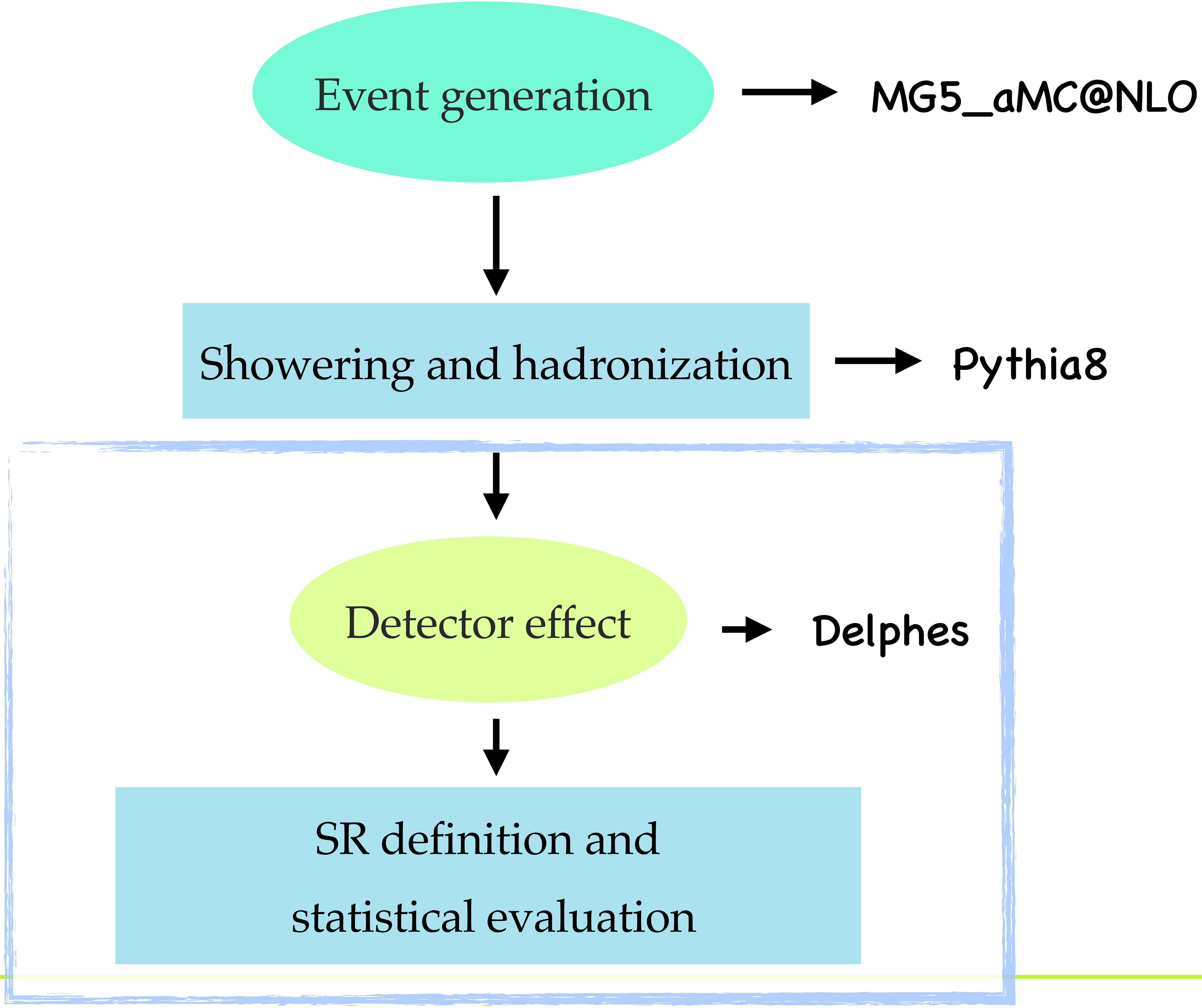
Correct (low) Relic abundance.

$$\Omega_{CDM} h^2 = (\leq)\, 0.120 \pm 0.001$$

Direct detection SI bounds from XENON1T

LHC searches recasting with CheckMATE

Drees, Dreiner, Schmeier, Tattersall, Kim '13
Kim, Schmeier, Tattersall, Rolbiecki '15
Dercks, Desai, Kim, Rolbiecki, Tattersall '16

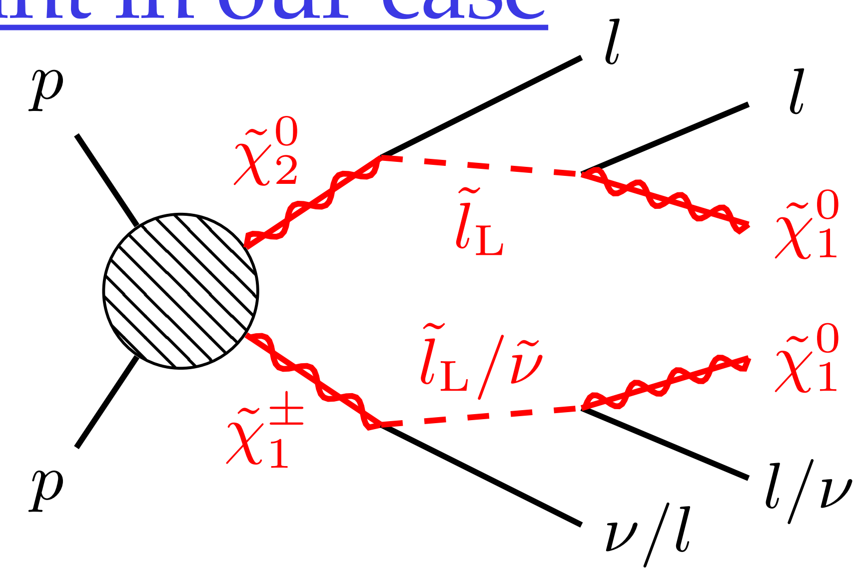


New analysis implementation

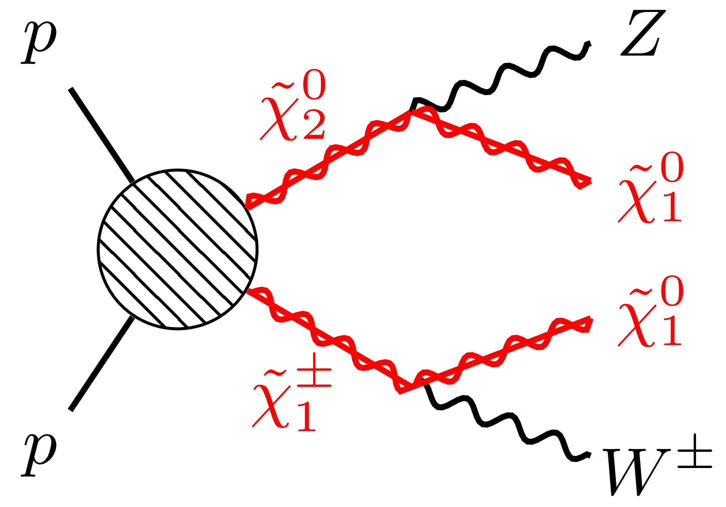
Most relevant in our case

Trilepton searches

- ATLAS [1803.02762]

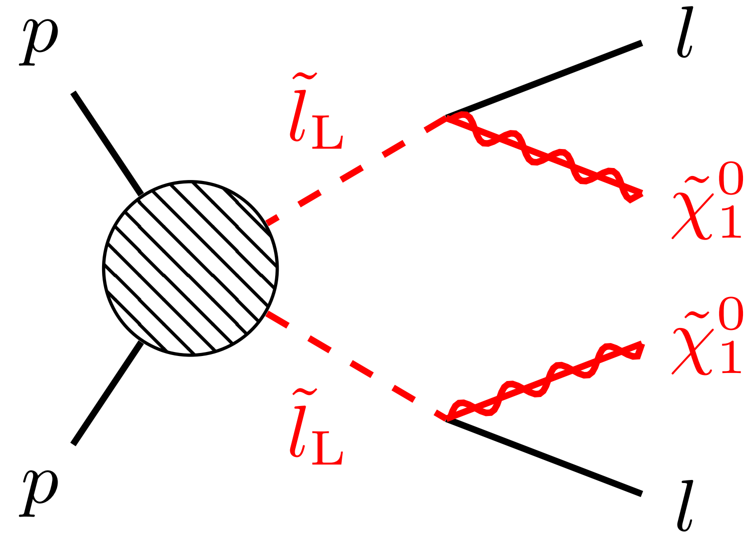


- ATLAS [1803.02762]



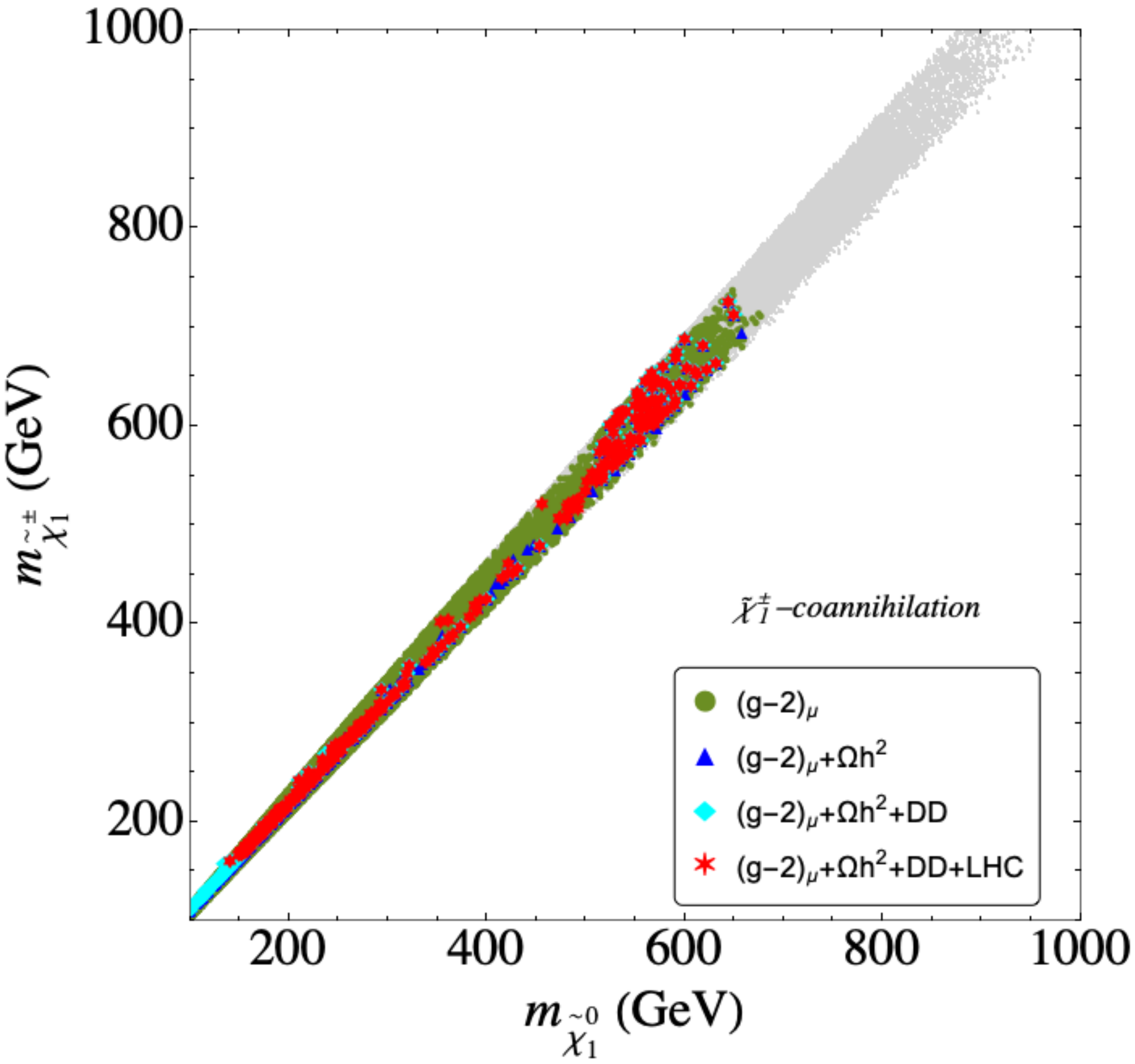
Dilepton searches

- ATLAS [1908.08215]



And, Compressed spectra searches.

Bino-Wino Co-annihilation (Correct abundance)



Bino-wino co-annihilation

$$100\ \text{GeV} \leq M_1 \leq 1\ \text{TeV}\ , \quad M_1 \leq M_2 \leq 1.1 M_1\ ,$$
$$1.1 M_1 \leq \mu \leq 10 M_1, \quad 5 \leq \tan\beta \leq 60,$$
$$100\ \text{GeV} \leq m_{\tilde{l}_L} \leq 1\ \text{TeV}, \quad m_{\tilde{l}_R} = m_{\tilde{l}_L}\ .$$

Upper and lower bounds from $(g-2)_\mu$ and LHC searches (including compressed spectrum) respectively.

NLSP mass upper bound around 750 GeV.

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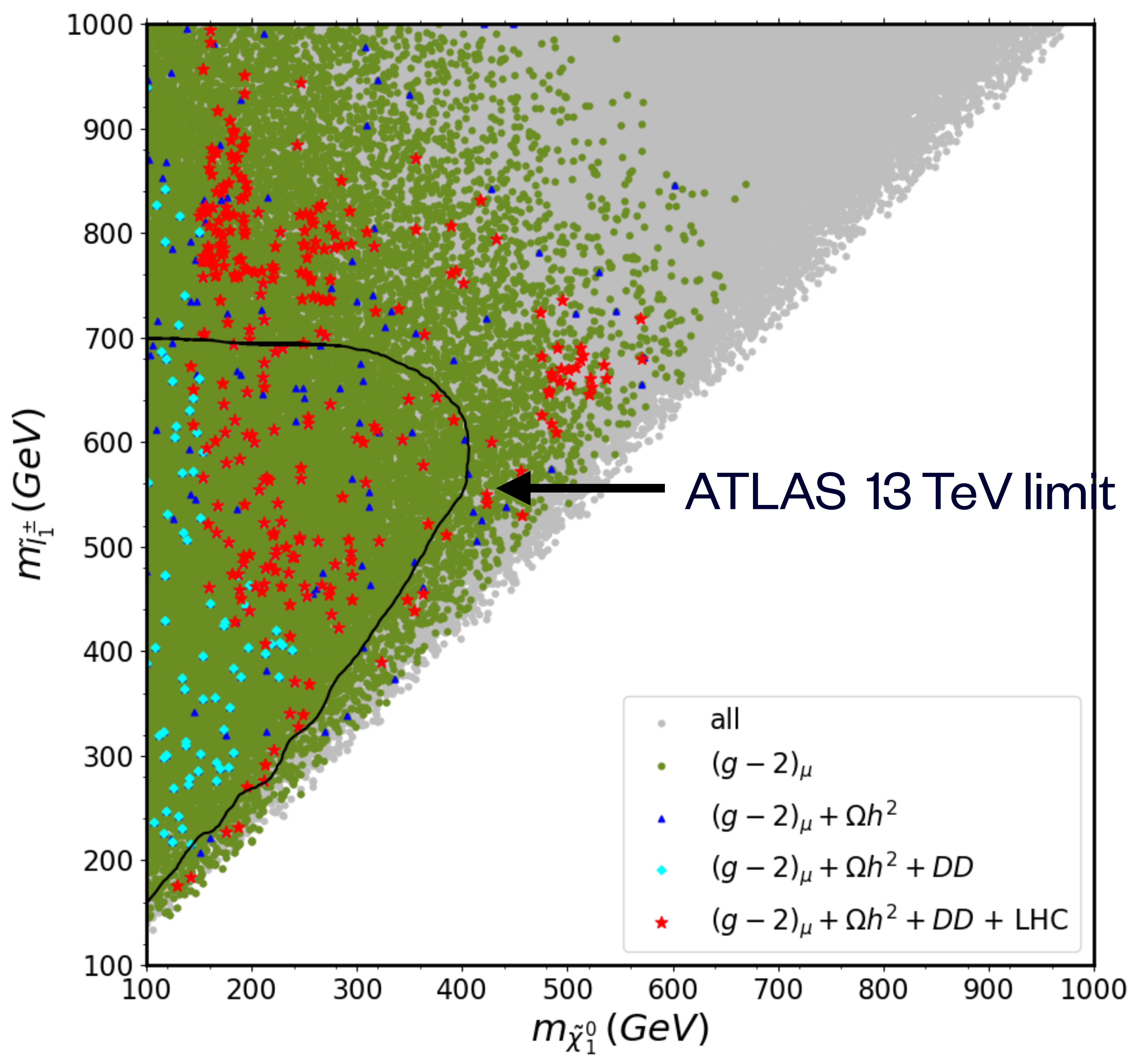
Results in the $m_{\tilde{\chi}_1^0} - m_{\tilde{l}_1}$ plane



Additional LHC bounds come from slepton searches.

- Slepton-pair production →($2l$ + missing E_T) provides important search channel

- Considerable BR for $\tilde{e}_L(\tilde{\mu}_L) \rightarrow \tilde{\chi}_1^{\pm}\nu_e(\nu_\mu)$

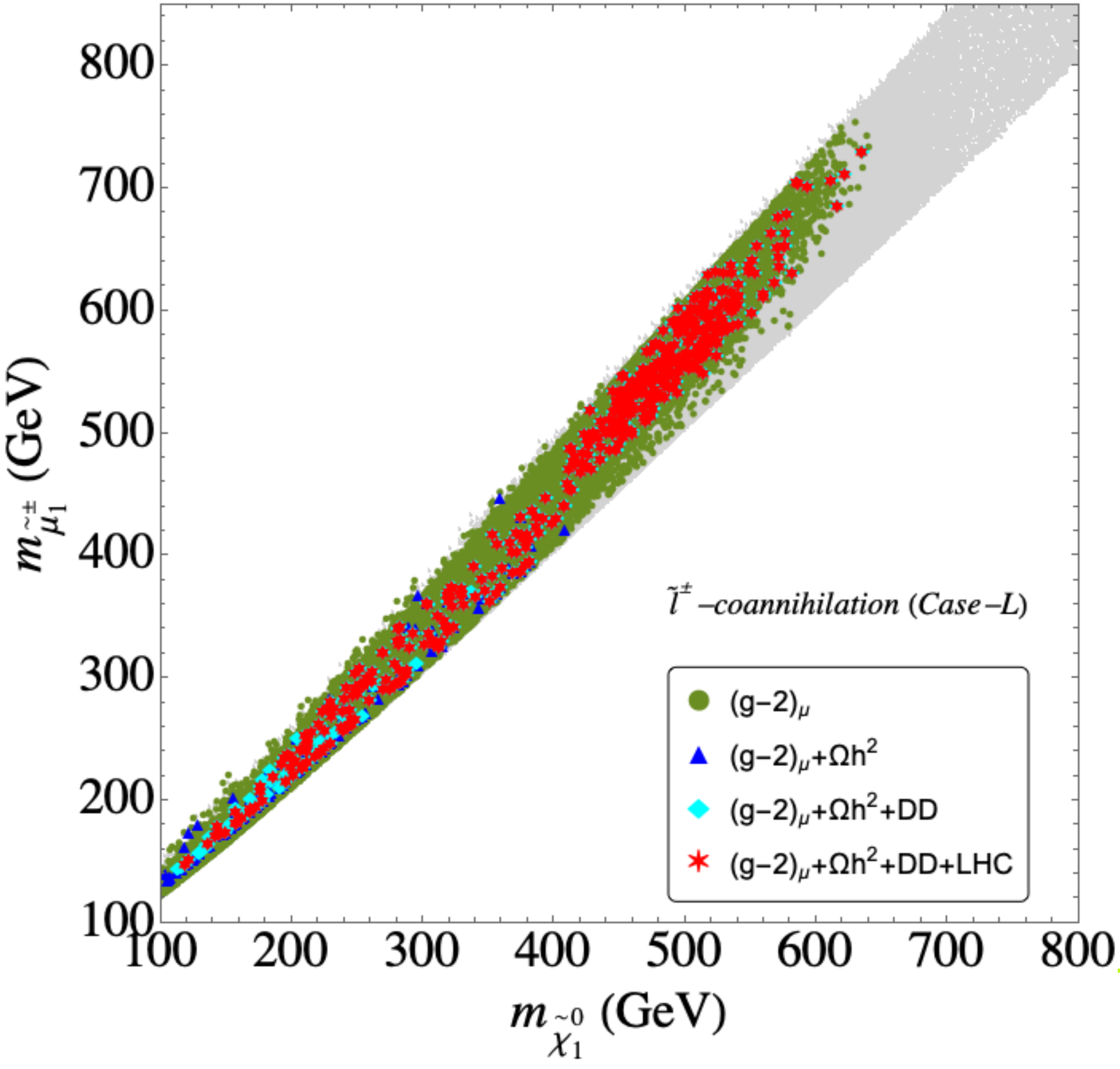
↓

Less no. of signal leptons.

Slepton Co-annihilation: Case-L

(Correct abundance)

Case-L: SU(2) doublet



$$100 \text{ GeV} \le M_1 \le 1 \text{ TeV}, \quad M_1 \le M_2 \le 10 M_1,$$
$$1.1 M_1 \le \mu \le 10 M_1, \quad 5 \le \tan\beta \le 60,$$
$$M_1 \text{ GeV} \le m_{\tilde{l}_L} \le 1.2 M_1, \quad M_1 \le m_{\tilde{l}_R} \le 10 M_1 .$$

The left-sleptons and sneutrinos are close in mass to the LSP. NLSP mass upper bound around 750 GeV.

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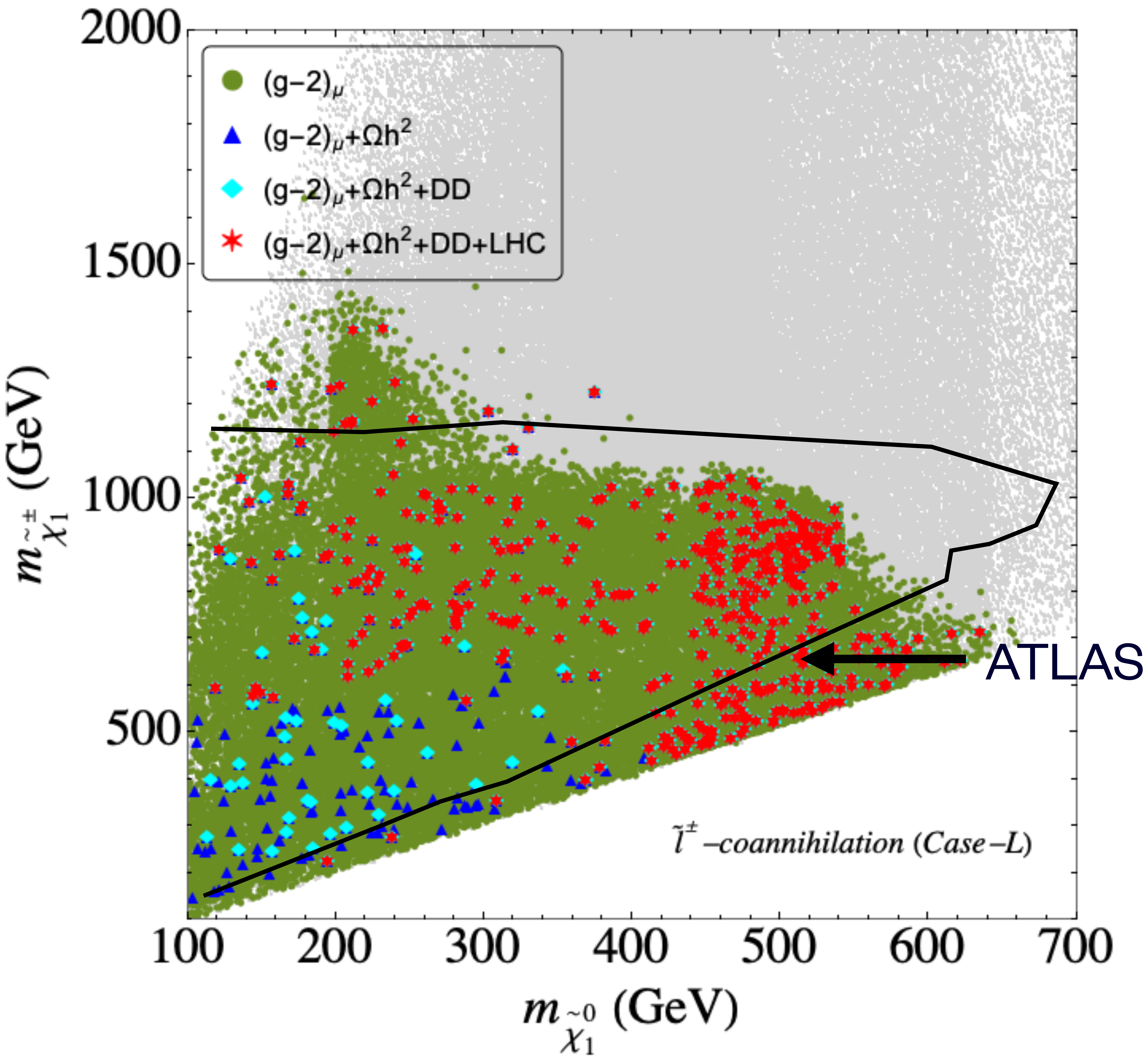
Slepton Co-annihilation: Case-L (Correct abundance)



Additional LHC bounds come from chargino plus heavier neutralino searches.

($3l$ + missing E_T) exclusion limit weakens

$\mathrm{BR}(\tilde{\chi}_1^{\pm} \to \tilde{\tau}_1 \nu_\tau)$ and $\mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau)$, $\mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\nu}\nu)$

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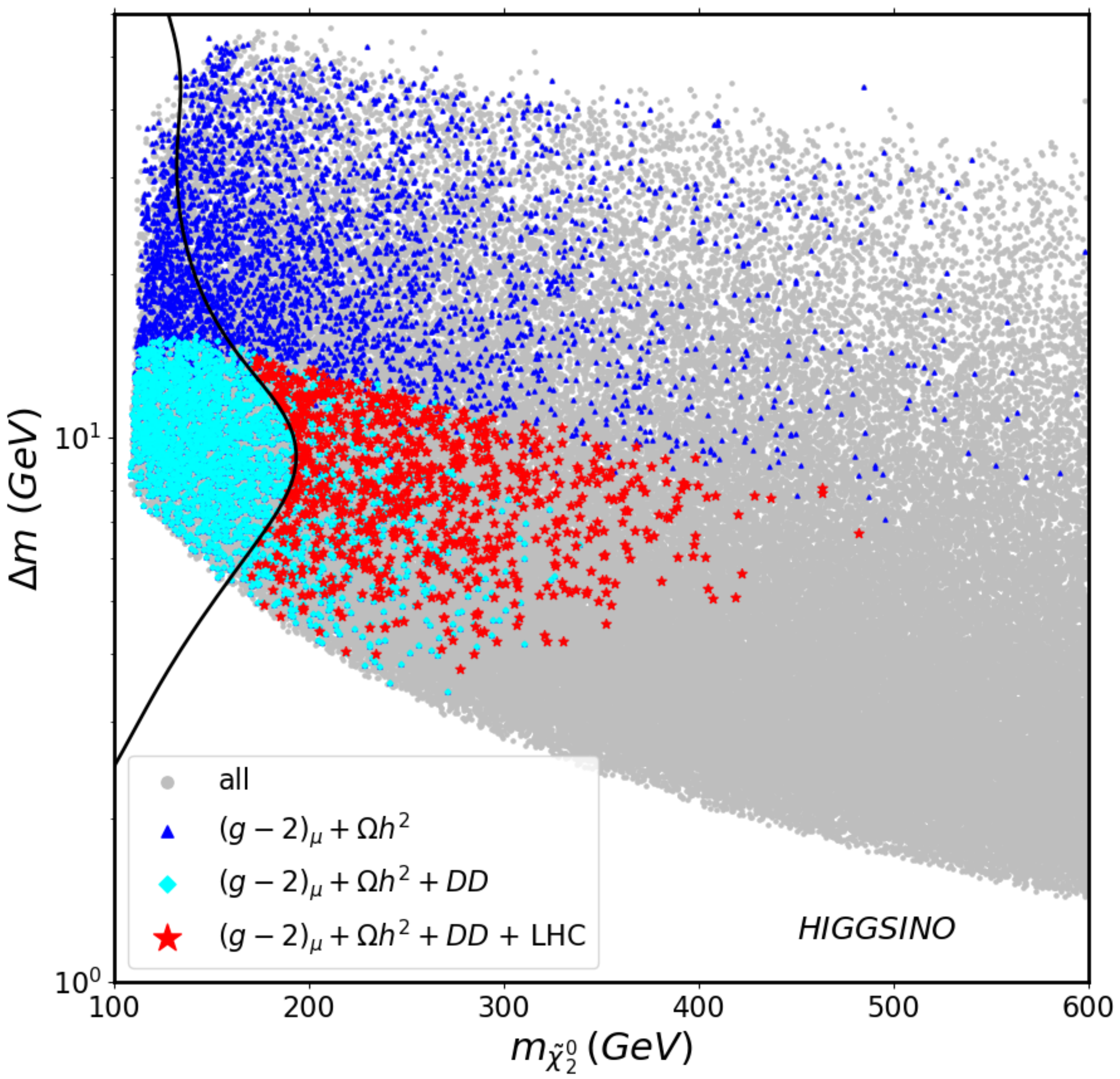
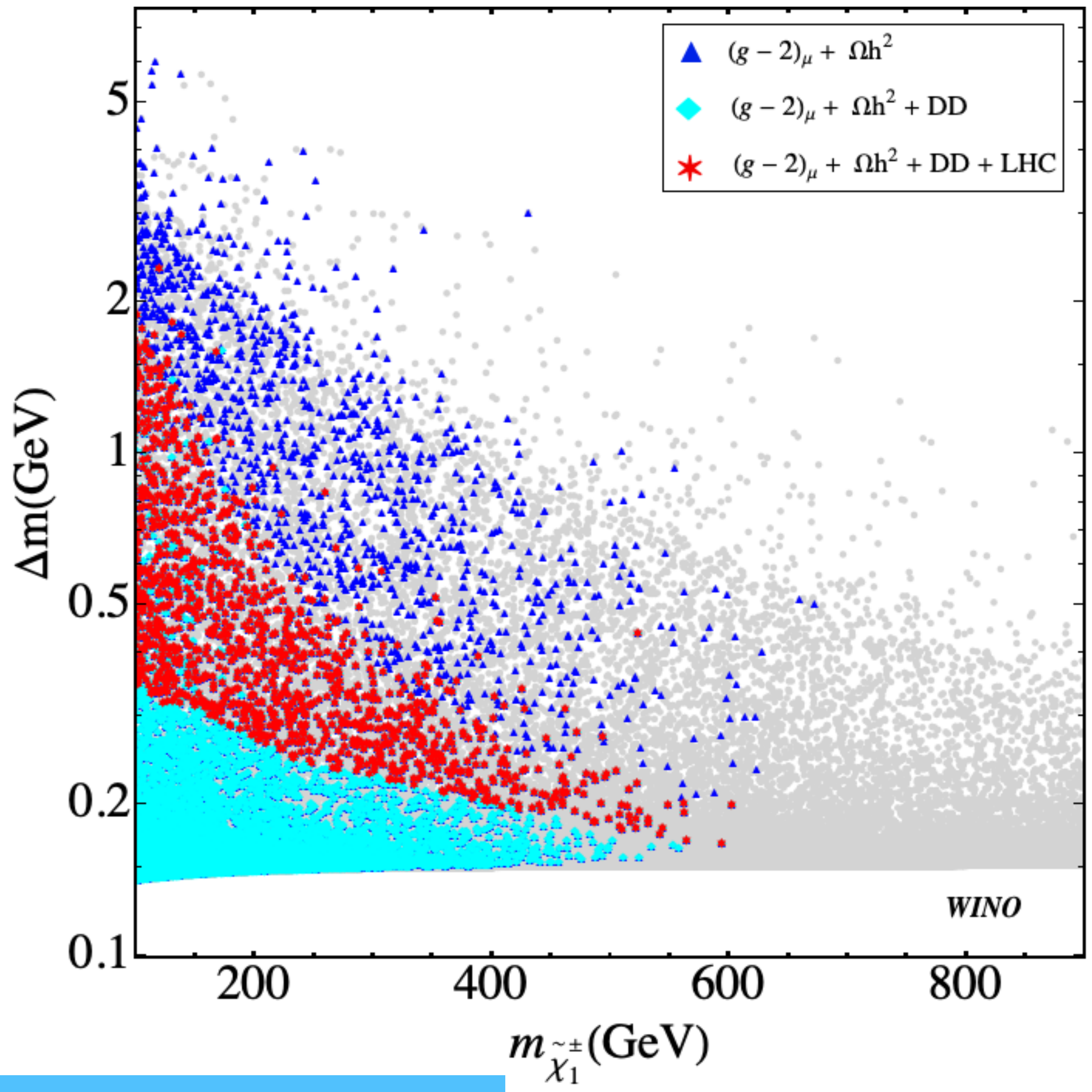
Higgsino and Wino:

(Only low relic abundance can be obtained)

Higgsino



Wino



Chargino-neutralino compressed spectrum searches are important for Higgsino while disappearing track searches are relevant for Wino in addition to slepton searches.

FUTURE DIRECT DETECTION AND LHC CONSTRAINTS WILL BE IMPORTANT FOR THESE SCENARIOS.

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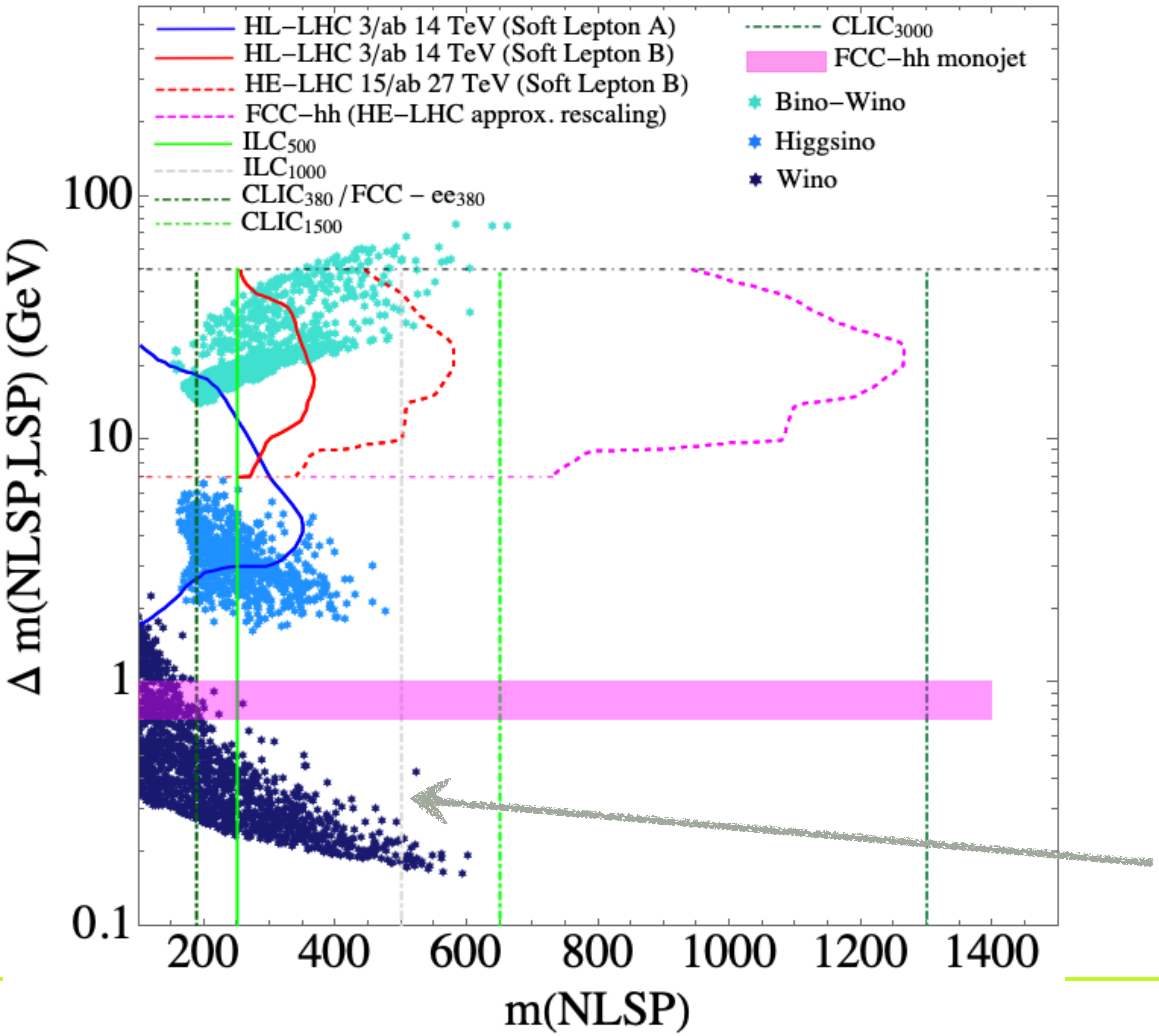
Future prospects (under abundant DM)



ILC- 1 TeV reach

Compressed Chargino-Neutralino spectrum at future lepton colliders has high hope.

'Wino and Higgsino Factory'

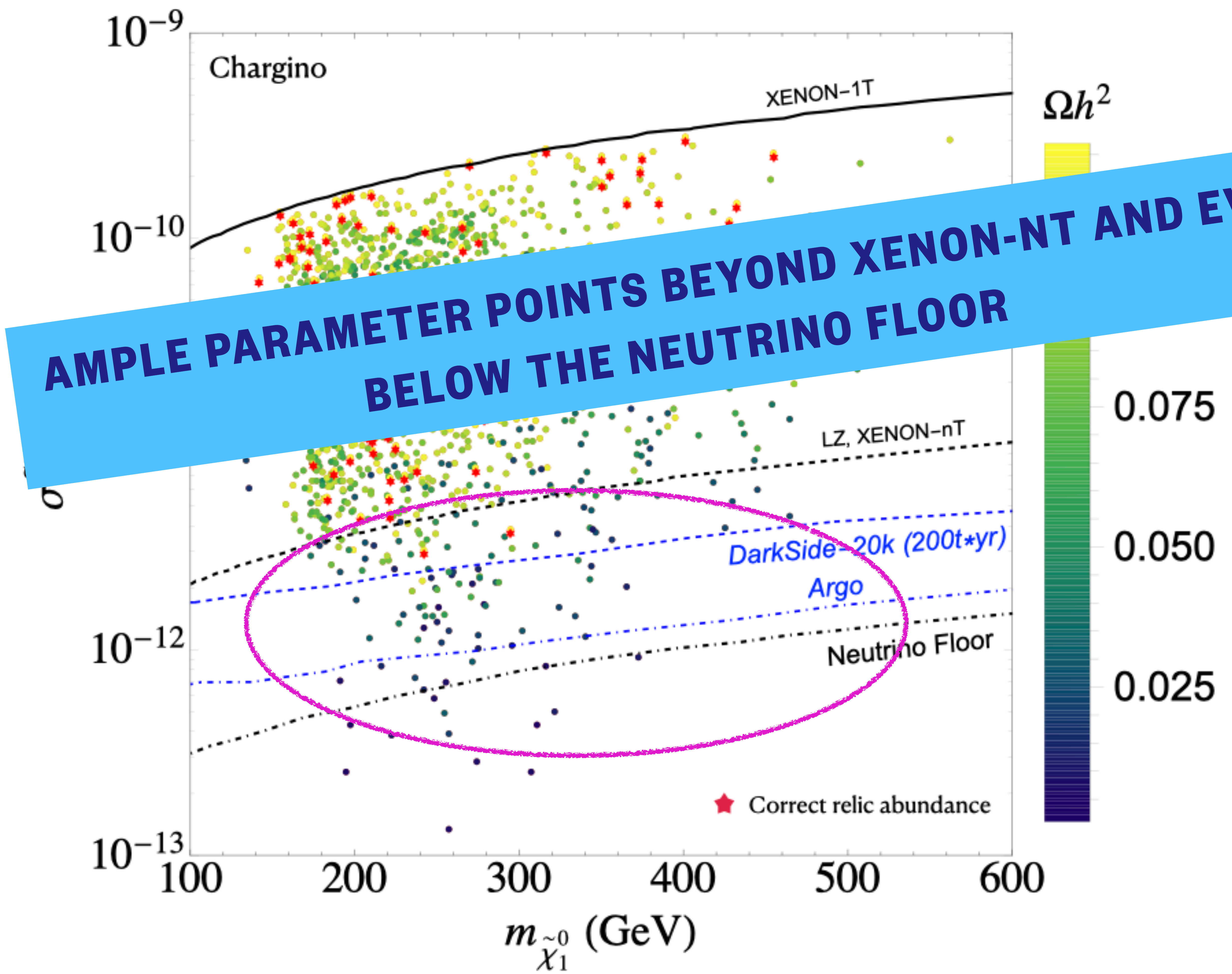
$$\Omega_{CDM}h^2 \leq 0.120 \pm 0.001$$

$$\Delta a_\mu = (25.1 \pm 5.9) \times 10^{-10}$$

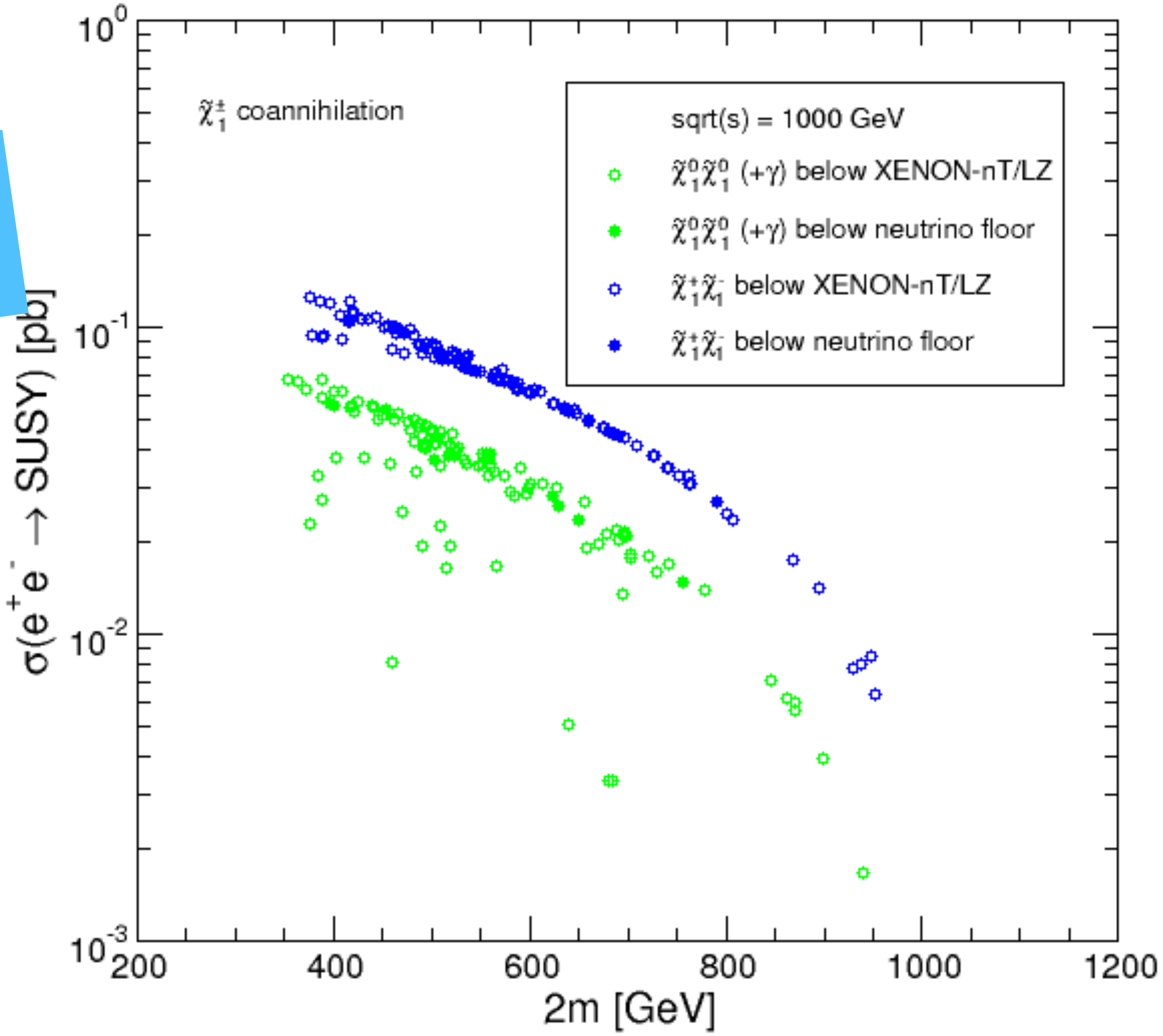
Direct detection SI bounds from XENON1T

DM Direct Detection and ILC- 1TeV complementarity

Chargino Coannihilation



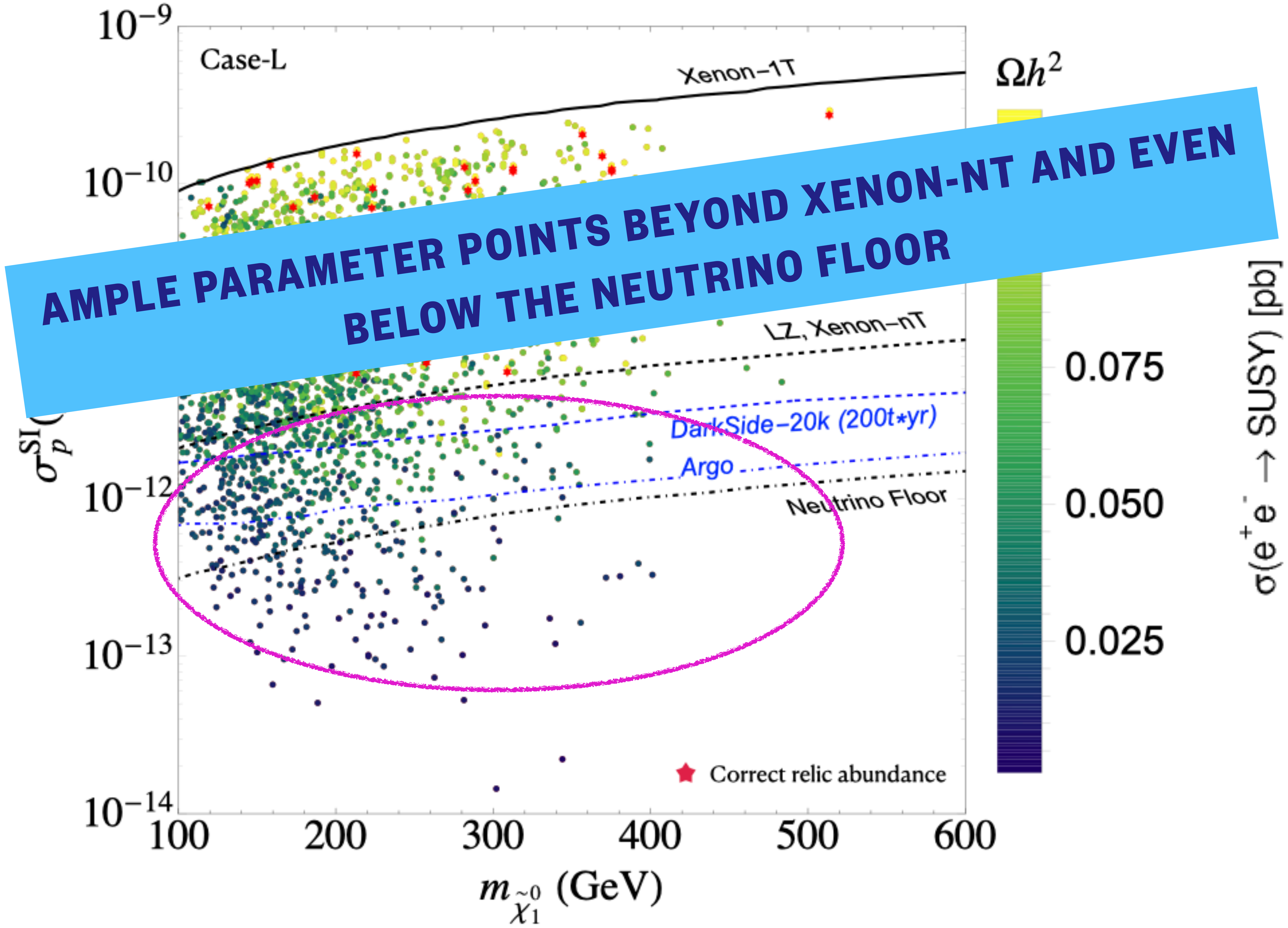
AMPLE PARAMETER POINTS BEYOND XENON-NT AND EVEN BELOW THE NEUTRINO FLOOR

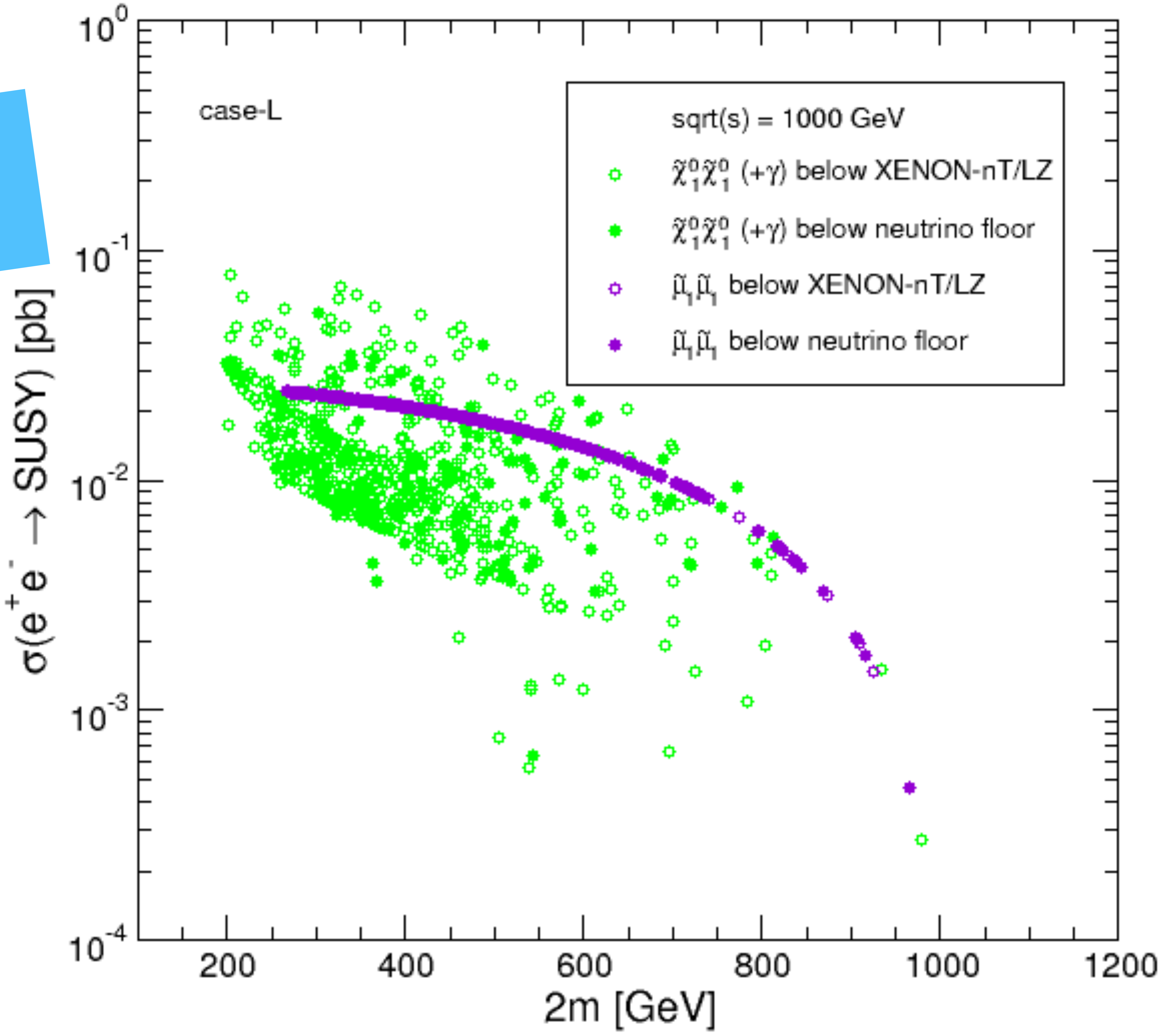


M.Chakraborti, S. Heinemeyer, IS, C. Shappacher **ARXIV: 2112.01389**

DM Direct Detection and ILC- 1TeV complementarity

Slepton Coannihilation (case-L)





M.Chakraborti, S. Heinemeyer, IS, C. Shappacher **ARXIV: 2112.01389**

Summary and Conclusions

- It is possible to constrain the EW MSSM with the help of indirect constraints along with the direct collider limits.
- DM and muon (g-2) constraint put effective upper limit on EW SUSY NLSP masses while LHC limits restrict the mass ranges from below.
- LHC exclusion bound strongly depends on EW gaugino composition. Proper recasting of ATLAS/CMS analysis relaxes the existing bound.
- Searches at future lepton colliders i.e. ILC (1 TeV) will be conclusive.
- ILC will play complementary role to future DM DD experiments.
- Contribution to Snowmass paper is ongoing and will be done on time.

THANK YOU!